

Suppressed B_s^0 decays at CDF

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We review three recent results of the CDF collaboration on B_s^0 suppressed decays: the first search for CP-violation in the $B_s^0 \rightarrow \phi\phi$ decay, where two CP-violating asymmetries expected to be zero in the Standard Model are measured, and the observation and the branching ratio measurements of $B_s^0 \rightarrow J/\psi f_0(980)$ and $B_s^0 \rightarrow J/\psi K^{(*)}$ decays.

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1. Introduction

In the past decade Tevatron experiments CDF and D0 have pioneered the physics of the B_s^0 meson with a broad program aimed at its exploration. Although significant samples of fully reconstructed B_s^0 decays have been collected allowing decisive progress on B_s^0 mixing, lifetime, decay width difference $\Delta\Gamma_s$ as well as CP-violation measurements, more precise investigations are ongoing. In this report, we review recent results of the CDF collaboration on B_s^0 suppressed decays: the first search for CP-violation in the $B_s^0 \rightarrow \phi\phi$ decay and the observation of $B_s^0 \rightarrow J/\psi f_0(980)$ and $B_s^0 \rightarrow J/\psi K^{(*)}$ decays.

Two features of the CDF II detector [1] are relevant for these measurements: the tracking and the trigger. A high resolution tracking detector provides an excellent resolution on B -meson decay length ($30\ \mu\text{m}$) and mass, typically about $10\ \text{MeV}/c^2$ for $B \rightarrow J/\psi X$ modes, that is pivotal for the observation of B_s^0 suppressed modes. This is achieved by double-sided silicon microstrips arranged in five cylindrical layers and an open cell drift chamber with 96 sense wires, all immersed in a 1.4 T solenoidal magnetic field. Signals of $B \rightarrow J/\psi X$ modes are efficiently collected by a dimuon trigger [1] with a $1.5\ \text{GeV}/c$ transverse momentum threshold, while the trigger on displaced vertex [2] allows the collection of hadronic decay modes like $B_s^0 \rightarrow \phi\phi$, through online measurement of impact parameters of charged tracks with a resolution ($48\ \mu\text{m}$) comparable with offline measurements.

2. First search for CP-violation in the $B_s^0 \rightarrow \phi\phi$ decay

The $B_s^0 \rightarrow \phi\phi$ decay belongs to the class of transitions of pseudoscalar mesons into two vector particles ($P \rightarrow VV$), whose rich dynamics involves three different amplitudes corresponding to the polarization states. In the Standard Model (SM) the dominant quark level process is described by the $b \rightarrow s$ “penguin” amplitude. Hence, the possibility to access New Physics (NP) through exchange of new virtual massive particles makes the $B_s^0 \rightarrow \phi\phi$ channel attractive. Indeed, the naïve SM expectation for polarization amplitudes has shown discrepancies with measurements of similar penguin decays [3], raising considerable attention to the so-called “polarization puzzle” [4]. Moreover, having a self-conjugate final state, the $B_s^0 \rightarrow \phi\phi$ decay is sensitive to the CP-violation in the interference between decay with and without mixing. Actually, the CP-violating weak phase $\phi_s^{B_s^0 \rightarrow \phi\phi}$ is predicted to be extremely small in the SM and measurement of nonzero CP-violating observables would indicate unambiguously NP.

The first evidence for the $B_s^0 \rightarrow \phi\phi$ decay has been reported by CDF in 2005 [6]. Using $2.9\ \text{fb}^{-1}$ of data, the branching ratio measurement was recently updated [7], $\mathcal{B}(B_s^0 \rightarrow \phi\phi) = (2.40 \pm 0.21(\text{stat.}) \pm 0.86(\text{syst.})) \times 10^{-5}$, in agreement with the first determination. Signal candidates are reconstructed by detecting $\phi \rightarrow K^+ K^-$ decays and are formed by fitting four tracks to a common vertex. Combinatorial background is reduced by exploiting several variables sensitive to the long lifetime and relatively hard p_T spectrum of B mesons, while the physics background, given by $B^0 \rightarrow \phi K^*(892)^0$ decay, is estimated by simulation not to exceed a 3% fraction of the signal. Signals of 295 ± 20 events are obtained by fitting the mass distribution. This data sample has allowed the world’s first polarization measurement [7] by analyzing the angular distributions of decay products, expressed as a function of helicity angles, $\vec{\omega} = (\cos \vartheta_1, \cos \vartheta_2, \Phi)$. The total decay

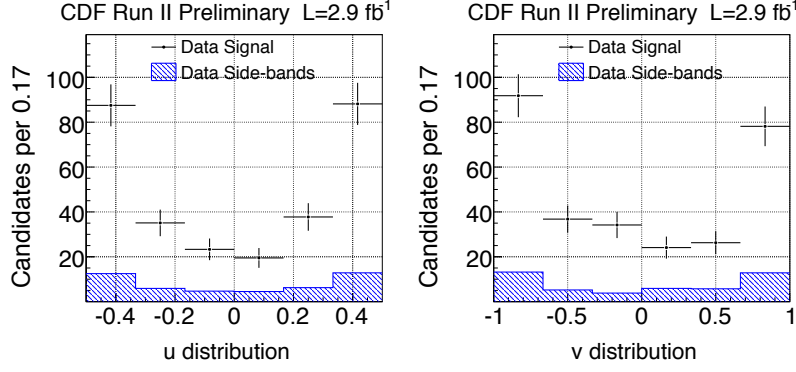


Figure 1: Distribution of u (left) and v (right) for $B_s^0 \rightarrow \phi\phi$ candidates. Black crosses are background-subtracted data; the blue histogram represents the background.

width is composed of three polarization amplitudes: two CP-even (A_0 and A_{\parallel}) and one CP-odd (A_{\perp}). The measured amplitudes result in a smaller longitudinal fraction with respect to the naïve expectation, $f_L = 0.348 \pm 0.041 \pm 0.021$, as found in other similar $b \rightarrow s$ penguin decays [3].

Present statistics of the $B_s^0 \rightarrow \phi\phi$ data sample are not sufficient for a suitable time-dependent analysis of mixing induced CP-violation as the case of the $B_s^0 \rightarrow J/\psi\phi$ decay. However, an investigation of genuine CP-violating observables which could reveal the presence of NP, such as triple products (TP) correlations, is accessible [8]. The TP is expressed as $\vec{p} \cdot (\vec{\epsilon}_1 \times \vec{\epsilon}_2)$, where \vec{p} is the momentum of one of the ϕ meson in the B_s^0 rest frame, and $\vec{\epsilon}_i$ are the polarization vectors of the vector mesons. There are two triple products in the $B_s^0 \rightarrow \phi\phi$ decay corresponding to interferences between CP-odd and CP-even amplitudes, one for transverse-longitudinal mixture, $\Im(A_0 A_{\perp}^*)$, and the other for the transverse-transverse term, $\Im(A_{\parallel} A_{\perp}^*)$. These products are functions of the helicity angles: the former is defined by $v = \sin\Phi$ for $\cos\vartheta_1 \cos\vartheta_2 \geq 0$ and $v = -\sin\Phi$ for $\cos\vartheta_1 \cos\vartheta_2 < 0$; the latter is defined by $u = \sin 2\Phi$. The u and v distribution for $B_s^0 \rightarrow \phi\phi$ candidates are shown in fig 1. Without distinction of the flavor of the B_s^0 meson at the production time (*untagged* sample), the following equation defines a CP-violating asymmetry:

$$\mathcal{A}_u = \frac{\Gamma(u > 0) + \bar{\Gamma}(u > 0) - \Gamma(u < 0) - \bar{\Gamma}(u < 0)}{\Gamma(u > 0) + \bar{\Gamma}(u > 0) + \Gamma(u < 0) + \bar{\Gamma}(u < 0)}, \quad (2.1)$$

where Γ is the decay rate for the given process and $\bar{\Gamma}$ is its CP-conjugate. An equivalent definition holds for v . Being proportional to $\sin\phi_s \cos\delta_i$, where δ_i are relative strong phases between the polarization amplitudes, in $B_s^0 \rightarrow \phi\phi$ these asymmetries are nonzero only in presence of NP [8].

The CDF collaboration has made the first measurement of \mathcal{A}_u and \mathcal{A}_v asymmetries in $B_s^0 \rightarrow \phi\phi$ using the data sample described above [9]. The asymmetries are obtained through an unbinned maximum likelihood fit. The sample is split into two subsets according to the sign of u (or v) of $B_s^0 \rightarrow \phi\phi$ candidates. The invariant mass distribution of each subset is fitted simultaneously in order to extract the signal asymmetry. The small fraction of physics background, such as $B^0 \rightarrow \phi K^*(892)^0$ as well as non-resonant decay $B_s^0 \rightarrow \phi K^+ K^-$ and “S-wave” contamination $B_s^0 \rightarrow J/\psi f_0(980)$, is neglected in the fit and its effect is accounted for in the assigned systematic uncertainties. Using a large sample of Monte Carlo (MC) data the detector acceptance and

the reconstruction requirements are checked against biases with a 0.2% accuracy. The background asymmetries are consistent with zero, and the final results for signal asymmetries are: $\mathcal{A}_u = (-0.7 \pm 6.4(\text{stat.}) \pm 1.8(\text{syst.}))\%$ and $\mathcal{A}_v = (-12.0 \pm 6.4(\text{stat.}) \pm 1.6(\text{syst.}))\%$. This measurement establishes a method to search for NP through CP-violating observables in $P \rightarrow VV$ decays without the need of tagging and time-dependent analysis, which requires high statistics samples.

3. Observation of the $B_s^0 \rightarrow J/\psi f_0(980)$ decay

The $B_s^0 \rightarrow J/\psi f_0(980)$ decay has attracted significant attention as a potential ‘‘S-wave’’ contamination to the $B_s^0 \rightarrow J/\psi \phi$ signal when the departure from the SM expectation of Tevatron measurement of mixed induced CP-violation was observed at level of about 1.5σ [5]. It was also suggested that enough signal of $B_s^0 \rightarrow J/\psi f_0(980)$ decays can be used to measure the CP-violating phase β_s as well, without need of angular analysis [11]. In addition, the CP-odd nature of the $J/\psi f_0(980)$ allows for measuring the lifetime of the B_s^0 CP-odd eigenstate, $1/\Gamma_s^{\text{odd}}$, that is the lifetime of the heavy-mass eigenstate if CP is conserved. This year the Tevatron experiments have quickly confirmed the observations of this mode [12] from LHCb and Belle collaborations [13]. In the following we review the CDF result of the ratio of branching fractions:

$$R = \frac{\mathcal{B}(B_s^0 \rightarrow J/\psi f_0(980))\mathcal{B}(f_0(980) \rightarrow \pi^+\pi^-)}{\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)\mathcal{B}(\phi \rightarrow K^+K^-)}, \quad (3.1)$$

where $\mathcal{B}(f_0(980) \rightarrow \pi^+\pi^-)$ and $\mathcal{B}(\phi \rightarrow K^+K^-)$ are fixed to PDG values [10], while $\mathcal{B}(B_s^0 \rightarrow J/\psi f_0(980))/\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)$ is measured using 3.8 fb^{-1} of data collected by the dimuon trigger.

The sample selection is performed by a neural network trained to maximize the separation between signal and background events. A threshold on the output of the neural network is chosen by maximizing $\varepsilon/(2.5 + \sqrt{N_b})$ [14], where ε is the signal reconstruction efficiency and N_b is the number of background events estimated from mass distribution sidebands. The background is dominated by a smooth combinatorial component. Physics backgrounds are studied using inclusive simulated decays of b -hadrons into J/ψ final states (fig. 2). The most prominent physics backgrounds in the $J/\psi \pi\pi$ spectrum are $B^0 \rightarrow J/\psi K^*(892)^0$ and $B^0 \rightarrow J/\psi \pi^+\pi^-$ decays.

The ratio $\mathcal{B}(B_s^0 \rightarrow J/\psi f_0(980))/\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)$ is evaluated as $N(B_s^0 \rightarrow J/\psi f_0(980))/N(B_s^0 \rightarrow J/\psi \phi)\varepsilon_{\text{rel}}$, where $N(B_s^0 \rightarrow J/\psi f_0(980))$ and $N(B_s^0 \rightarrow J/\psi \phi)$ are the number of signal events of $B_s^0 \rightarrow J/\psi f_0(980)$ and $B_s^0 \rightarrow J/\psi \phi$ respectively, extracted by performing an unbinned extended maximum likelihood fit of the candidates mass distribution in $[5.26; 5.5] \text{ GeV}/c^2$ (fig. 2); ε_{rel} is the relative efficiency for the reconstruction of the two decays. The latter is evaluated by MC simulation, where $B_s^0 \rightarrow J/\psi \phi$ candidates are generated based on CDF preliminary results [15],¹ while $B_s^0 \rightarrow J/\psi f_0(980)$ candidates are modeled by a Flatté distribution whose parameters are fixed to the BES experiment results [16]. We found $N(B_s^0 \rightarrow J/\psi f_0(980)) = 571 \pm 37(\text{stat.}) \pm 25(\text{syst.})$ with significance much greater than 5σ , and finally $R = 0.292 \pm 0.020(\text{stat.}) \pm 0.017(\text{syst.})$. The measurement is in good agreement with determinations by other experiments and it is the most accurate result to date.

¹ As a strong phase δ_{\parallel} is not measured we use the world average value from $B^0 \rightarrow J/\psi K^{0*}$ decays [10].

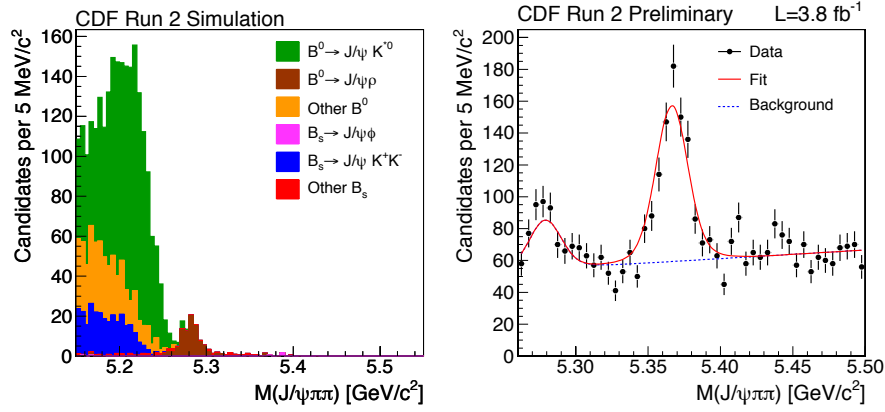


Figure 2: Left: stacked histogram of physics backgrounds in $J/\psi\pi\pi$ mass distribution from simulation. Right: fit to the $J/\psi\pi\pi$ mass distribution.

4. First observation of $B_s^0 \rightarrow J/\psi K^{(*)}$ decays

The two Cabibbo-suppressed decays $B_s^0 \rightarrow J/\psi K^{*}(892)^0$ and $B_s^0 \rightarrow J/\psi K_S$ allow disentanglement of penguin contributions in the decays $B_s^0 \rightarrow J/\psi \phi$ and $B^0 \rightarrow J/\psi K_S^0$, respectively. The $B_s^0 \rightarrow J/\psi K^{*}(892)^0$ decay could be used for the measurement of $\Delta\Gamma_s$ and polarization amplitudes, and $B_s^0 \rightarrow J/\psi K_S$ for measurement of $1/\Gamma_s^{\text{odd}}$. The $B_s^0 \rightarrow J/\psi K_S$ decay can also yield information on the γ angle of the unitarity triangle [17].

The CDF collaboration has recently reported the first observation of these modes and the measurement of their branching ratios in 5.9 fb^{-1} of data selected by the dimuon trigger [18]. The sample selection was optimized maximizing the sensitivity for either finding evidence of a signal at 3σ , or excluding it at the same confidence level; for the $B_s^0 \rightarrow J/\psi K_S$ the selection is based on a neural network, while for $B_s^0 \rightarrow J/\psi K^{*}(892)^0$ a simpler cut-based analysis is performed, in both cases exploiting vertexing and kinematic discriminating variables. Both analyses have two common background contributions: the combinatorial background and the partially reconstructed background where γ , π or K of multibody decays are not reconstructed. Other physics backgrounds, such as $\Lambda_b \rightarrow J/\psi \Lambda$ for $B_s^0 \rightarrow J/\psi K_S$ or $B_s^0 \rightarrow J/\psi \phi$ for $B_s^0 \rightarrow J/\psi K^{*}(892)^0$, give negligible contributions. A binned maximum likelihood fit to the mass distribution of the candidates has been performed to extract the signal yields (fig. 3): 64 ± 14 $B_s^0 \rightarrow J/\psi K_S$ and 151 ± 25 $B_s^0 \rightarrow J/\psi K^{*}(892)^0$ signal events have been observed, both with a significance greater than 5σ . Branching fractions are normalized to rates of the corresponding favored modes, $\mathcal{B}(B^0 \rightarrow J/\psi K_S^0)$ and $\mathcal{B}(B^0 \rightarrow J/\psi K^{*0})$, and relative efficiency of reconstruction is evaluated by MC simulation. The branching ratio of the favored decays are fixed to their PDG values [10] and the fragmentation-fraction f_s/f_d is fixed to the most recent CDF measurement of $f_s/(f_u + f_d)\mathcal{B}(D_s \rightarrow \phi\pi)$ [19] combined with PDG value of $\mathcal{B}(D_s \rightarrow \phi\pi)$. Finally, the measured branching ratios are $\mathcal{B}(B_s^0 \rightarrow J/\psi K^{*}(892)^0) = (8.3 \pm 1.2(\text{stat.}) \pm 3.5(\text{syst.})) \times 10^{-5}$ and $\mathcal{B}(B_s^0 \rightarrow J/\psi K_S) = (3.5 \pm 0.6(\text{stat.}) \pm 0.6(\text{syst.})) \times 10^{-5}$.

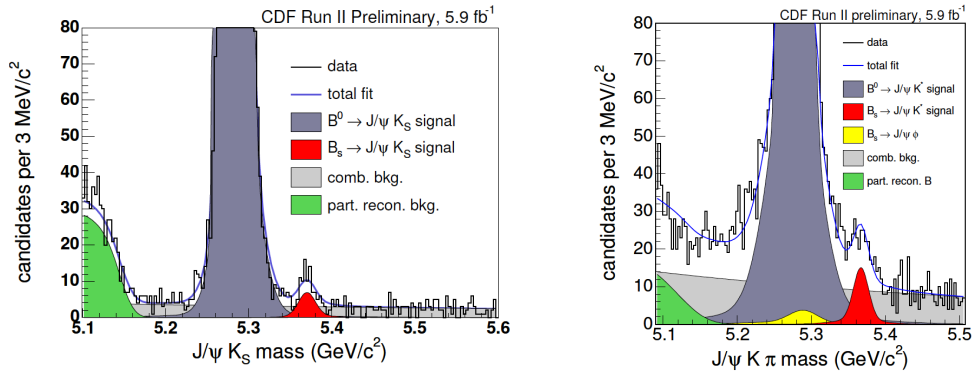


Figure 3: Invariant mass distribution for $J/\psi K_S^0$ (left) and for $J/\psi K \pi$ (right) with fit including the different contributions.

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